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ABSTRACT

This paper summarizes research in modern cognitive theory that relates to the role of computer drill and practice programs in learning and describes a prototype program that exemplifies recommended characteristics. Focus is on four major issues that are relevant to the design and optimization of computer drills: interference, spaced practice, spaced review, and capacity of short term memory. Implications for the design of computer drills are suggested, including the need to: (1) present similar items in close proximity to each other; (2) emphasize differences between similar items; (3) provide a mechanism to keep track of the items that a particular learner was working on during the last session; (4) provide a mechanism for reviewing items previously learned, based on the amount of time since the learner last responded to each item; (5) utilize increasing ratio-review; (6) present only a few items of information to the learner at once; and (7) combine meaningful stimuli into a single stimulus as chunking occurs. Some areas for future research are suggested, and 32 references are listed. (LMM)

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Cognitive Psychology and Its Implications for Designing Drill and Practice Programs for Computers

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Abstract

This paper summarizes important research in modern cognitive theory which relates to the role of computer drill and practice programs in learning. Several topics in the cognitive literature which have important practical implications to the design of computer drill and practice programs are also examined. In addition, the paper describes a prototype drill and practice program which exemplifies the characteristics recommended for drill and practice and also suggests some areas for future research.

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Cognitive Psychology and Its Implications

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Introduction

The computer manifests many characteristics which allow it to be potentially the most effective and efficient means of providing drill and practice. However, many of the drill and practice programs being produced today are poorly designed from a psychological standpoint and therefore probably do not provide drill and practice in the most effective and efficient means possible. Most computer drills pattern the traditional flashcard strategy which ignores some of the most basic principles derived from research in cognitive psychology. This paper focuses on four major issues in the cognitive literature which are relevant to the design and optimization of computer drills. These four issues are: (a) interference, (b) spaced practice, (c) spaced review, and (d) capacity of short-term memory. Each issue will be explored by summarizing representative research and findings, then implications for the design of computer drills are suggested. In the latter part of the paper a prototype drill and practice program which exemplifies several of the characteristics recommended for drill and practice will be described. Finally, some areas for future research related to computer drill and practice will be given.

Rationale

Why should one be concerned with the optimization of computer drills? One reason is that recent research in modern cognitive learning theory suggests that the role of drill and practice in learning may be more important than many people realize. The research that suggests

this is that related to the area of automaticity of subskills. This idea is based on the view that in order to perform complex intellectual tasks such as reading, computing, or computer programming many of the subskills involved have to be automatized. That means that the learner must be able to perform these subskills seemingly without thinking or--automatically.

The reason subskills need to be automatized is attributed to the limited capacity of working memory. Because the capacity of working memory is limited the number of mental operations that can be performed at one time is limited. In order for learners to perform well on complex tasks which involve many subprocesses or operations, performance of these subprocesses must be automatic so that attention can be devoted to the more intricate and complicated aspects of the total task. In other words, if the student is required to concentrate a great deal of working memory on the performance of one of the subskills, performance on the higher level skill will be attenuated. The implication of this is that certain skills must not only be mastered but must be brought to a state of automaticity.

The role of automaticity in learning has been shown in studies by Schneider and Shiffrin (1977) and Shiffrin and Schneider (1977). These studies show that a skill which once consumed a great deal of mental capacity can be brought to an automatized state at which it ceases to consume the mental capacity it did previously.

The 1982 study of Beck, Perfetti, and McKeown as well as numerous other studies (Frederikson, 1978; Jackson & McClelland, 1979; Perfetti & Hogaboam, 1975) have shown that in reading, speedy and efficient word-recognition and word understanding is critical in order to allow the reader to concentrate on such things as concepts and theme. In

performing mathematical computations, the simple underlying algorithms must be automatized so that the person can perform them quickly and without error (Brown & Burton, 1978).

The concept of automaticity also suggests that bad performance on complex skills should be evaluated and remediated in terms of subskill automaticity. Data from Hunt (1975) shows that a group of students considered to be of high verbal ability differed extremely from a group of students considered to be of low verbal ability in terms of letter recognition skills.

Lesgold and Resnick (1982) provide data which suggest that word recognition can be improved by additional training in subword recognition and that reading comprehension skills can be improved by additional training in vocalizing individual words.

Brown and Burton (1978) present evidence that student errors in mathematical computation can be analyzed in terms of bugs in the underlying subprocesses. The key then is to help students not only master critical subskills but to automatize them as well.

Other ways to automatize subskills may eventually be found, but at present practice is the answer. The question then to be asked is how does one design computer drill and practice programs which lead to skill automaticity most efficiently. The four issues to be reviewed in this paper should suggest ways in which to optimize computer drills. It will be noted that computers may be the only medium with the capabilities of capitalizing fully upon these suggestions.

Interference

The first issue concerns the degree to which computer drills take into account the amount of interference that may be present in learning the material. This issue is particularly relevant to drills which attempt to teach paired-associate tasks or discriminations. Students practicing their math facts, the correct spelling of a list of words, or learning a group of sight words would be examples of tasks in which the potential for interference is great. Basically, interference describes the phenomenon that the linking of one stimulus with a response is reduced by additional linkings of other items and reduces the probability that future linkages will be retained. The first type of interference, where new linkings interfere with old ones, is referred to as retroactive interference. The second type, where old linkings interfere with the formation of new ones, is referred to as proactive interference. Interference is largely the cause of increased difficulty in learning a set of items as more items become involved.

The effects of interference on learning were first described by McGeoch (1932) and have since been studied extensively by such researchers as Postman (1961, 1971) and Underwood (1964). The experiments usually involve paired-associate learning where students are asked to learn two different lists of word pairs. One group of students learns lists in which the same keywords are paired with different words on each list. The second group of students learn lists in which the keywords on one list are not the same keywords on the second list. The first group performs less well due to the different counterpart words for the same keyword interfering with one another. A particularly good illustration of the large effect on learning which can be produced by interference is provided by an experiment by Keppel, Postman, and

Zavortink (1968). In this experiment subjects learned 36 successive lists of word pairs at 48-hour intervals. Before learning each new list subjects were tested on the previous list and then learned the new list to a criterion of one perfect recital. The results of the tests given prior to learning each new list showed that the percentage of recall progressively declined as more lists were learned. The decline was from an average of 70% recall for the first list to only 5% recall for the 35th and 36th lists. This shows the powerful effect that proactive interference can produce. Interference also applies in learning tasks which involve learning sets of single sentences (Bobrow, 1970), or learning stories which are similar (Lewis and Anderson, 1976; Anderson and Bower, 1973).

Implications. The foregoing overview of the effects of interference in learning suggests that computer drills should be designed so as to minimize the amount of interference present in a learning situation. If the pool of items to be learned is large, only a few of the items should be presented at once. Once a subset of items has been learned new items should be progressively introduced while reviewing systematically those already learned.

Items which are similar and may be confused should be presented in close proximity to one another so that the student can observe and note the differences. It may even be possible to emphasize the differences between the two items when they are initially presented in the drill. As the drill progresses the differences could be diminished until the items return to their normal condition.

Spaced Practice

The second issue concerns the degree to which computer drills allow for the spacing of practice sessions. There is much evidence in the literature to suggest that short, spaced periods of practice give better results than long concentrated practice periods (see Anderson, 1980). Studies on the effects of spacing have shown that the probability of recall of items increases systematically as practice periods are spaced (Madigan, 1969; Gay, 1973). The reason spaced practice is considered to be more effective than massed practice is that the learning context on each occasion is somewhat different thus causing the information to be encoded somewhat differently each time. The spacing effect appears to be very robust and has been repeatedly shown with many different types of material. Bray (1948), for example, reported an experiment which showed that subjects could learn the Morse code with 4 hours a day of practice as rapidly a subjects who practiced 7 hours a day. The 7-hour a day subjects were apparently wasting the additional 3 hours of practice they were receiving per day.

A study by Reynolds and Glaser (1964) demonstrated the relative ineffectiveness of massed practice following initial learning. They investigated the effect of massed versus spaced practice on the learning of ten topics in biology. Subjects who received a massed practice condition were compared with subjects who received a spaced practice condition in which the practice materials were split into three parts and presented at spaced intervals during the instruction. Results indicated that spaced practice was more effective than an equal amount of massed practice. Gay (1973) showed that spaced practice in the application of algebra rules was superior to massed practice. Spacing effects have been demonstrated in free recall and cued recall

of paired associates, recall of sentences, and in the recall of textbook material (Rothkopf and Coke, 1973, 1966; Reynolds and Glaser, 1964).

Implications. The research on spaced practice suggests that learning environments in which computer drills are used should accommodate and encourage the spacing of practice sessions. Also, computer drills should include the capability of allowing the learner to stop and resume practice sessions without having to go back to the beginning of the drill. In other words, the learner should be able to resume a drill picking up with the same items that he or she was working on during the previous session. This requires that a record be kept on each individual learner to keep track of what items that learner was working on during the last session.

Spaced Review

The need for mechanisms to aid the learner in retaining mastered material has been shown in studies such as that by Hannum (1973) in which he reported that less than a third of a group of freshman math students were able to retain mastered skills for more than a week. A study by Layton (1930) indicated that only about one-third of first year algebra material is retained after a one-year period.

Spaced review has been shown to be a significant means of enhancing retention of learned material. Madigan (1969) presented subjects with 48 words to be recalled later. Some of the 48 words were presented twice, others only once. Subjects recalled twice presented words better than once presented words and the probability that a twice presented word would be recalled was a function of the spacing of the two presentations of the word within the sequence. In other words, the

further apart the two presentations of a word in the sequence, the higher was the probability for recalling that word, indicating that retention improves with increased spacing between exposure to the material.

The powerful effect of spaced review was demonstrated in a study by Peterson, Ellis, Toohill, and Kloess (1935). These researchers found that reviews placed one and nine days after initial learning were as effective as reviews placed two, three, and seven days after initial learning. They also showed that a second review was more effective than a first.

Another study, this time by Tiedeman (1948) found that with two intervening review tests learners were able to retain for 63 days the same amount of information that would have been retained for only one day without the reviews. Gay (1973) demonstrated the superiority of an early and late review over two early or two late reviews. Other studies have shown these same superior effects for spaced review over massed review (Ausubel and Youssef, 1965; Saxon, 1981).

Implications. The implications of research on spaced review suggest that computer drills should provide a mechanism for allowing the learner to review items previously learned based on the amount of time which has passed since the learner last responded to that item. This could be done by setting up a series of review stages allowing mastered items to be reviewed at different stages, say after a day, then after a week, then after a month.

Another way to approach this might be to provide increasing-ratio review where the ratio of new items to review items changes as the student progresses through the drill. When the student first begins the

drill all the items will be new items. As the student masters items, these become review items and are reintroduced systematically into the drill. Toward the end of the drill most of the items the student will be working with will be review items. Drills which are structured in this way could be used very effectively for the purpose of skill maintenance in addition to initial learning.

Capacity of Short-term Memory

The fourth issue is concerned with the degree to which computer drills allow for the limited capacity of short-term memory. Depending on the type of material involved, the number of stimuli the brain can work with at one time is approximately seven (Miller, 1956). Although we know that seven (plus or minus two) seems to be the magic number we do not know exactly what constitutes a single stimulus. For example, a person can hold seven or eight single digit numbers in memory but is this really one stimulus or seven stimuli. Is remembering a sentence one stimulus or does each word in the sentence constitute a stimulus?

The way to make sense out of this apparent variability in the capacity of short-term memory is chunking. A good example of chunking is given by Martin (1973, Chap. 19) and involves a man learning to decipher Morse code. At first, the man hears each dit and dah as a separate chunk. Later, he begins to organize these sounds into meaningful groups to form letters and the letters become the chunks. Eventually, letters become words and words become whole phrases. The amount of information that the man is able to deal with at one time has been increased dramatically by chunking or the combining into one stimulus items which were previously separate stimuli.

Implications. The limited capacity of short-term memory suggests that only a few items or meaningful chunks of information should be presented to the learner at once. In early practice sessions, items should be the smallest stimulus possible. In subsequent practice sessions, as chunking occurs, meaningful groups of stimuli may be considered to be single items. For example, beginning chemistry students could first learn the abbreviations for single elements found on the periodic table of the elements (e.g., Na=sodium, H=hydrogen, etc.). Then these could be combined into chemical compounds (e.g. NaCl), and finally into common whole equations which chemists recognize automatically.

A Prototype Drill and Practice Program

Table 1 summarizes these issues and their implications for the design and optimization of computer drills. While probably none of these issues is new or unfamiliar to instructional designers it is my observation that these issues are not being considered to the degree that they should be in the design of computer drill and practice programs. The next section of this paper is intended to summarize the implications from the table and combine them into a picture of what a computer drill and practice program might look like in order to be consistent with the literature cited above.

The drill and practice program to be described is one designed by Paul F. Merrill and John Hoffman at Brigham Young University and is based on earlier work done by Richard C. Atkinson at Stanford University (Atkinson, 1974). In this computer drill and practice program each student's response history is used to alter the remaining instruction in order to optimize the learning process for that student.

Table 1

Some Issues and Implications for Computer Drill and Practice Programs.

Issues	Implications
Automaticity of subskills	Provide practice in basic subskills before moving on to more complex skills. Evaluate and remediate performance in skills in terms of bugs in subskill performance.
Interference	If total number of items to be learned is large introduce only a few of the items at once. Present similar items in close proximity to each other. Emphasize differences between similar items.
Spaced practice	Provide a mechanism to keep track of the items that a particular learner was working on during the last session.
Spaced review	Provide a mechanism for reviewing items previously learned based on the amount of time which has passed since the learner last responded to each item. Utiiize increasing ratio-review
Capacity of short term memory	Present only a few items or meaningful "chunks" of information to the learner at once. As chunking occurs, combine meaningful stimuli into a single stimulus.

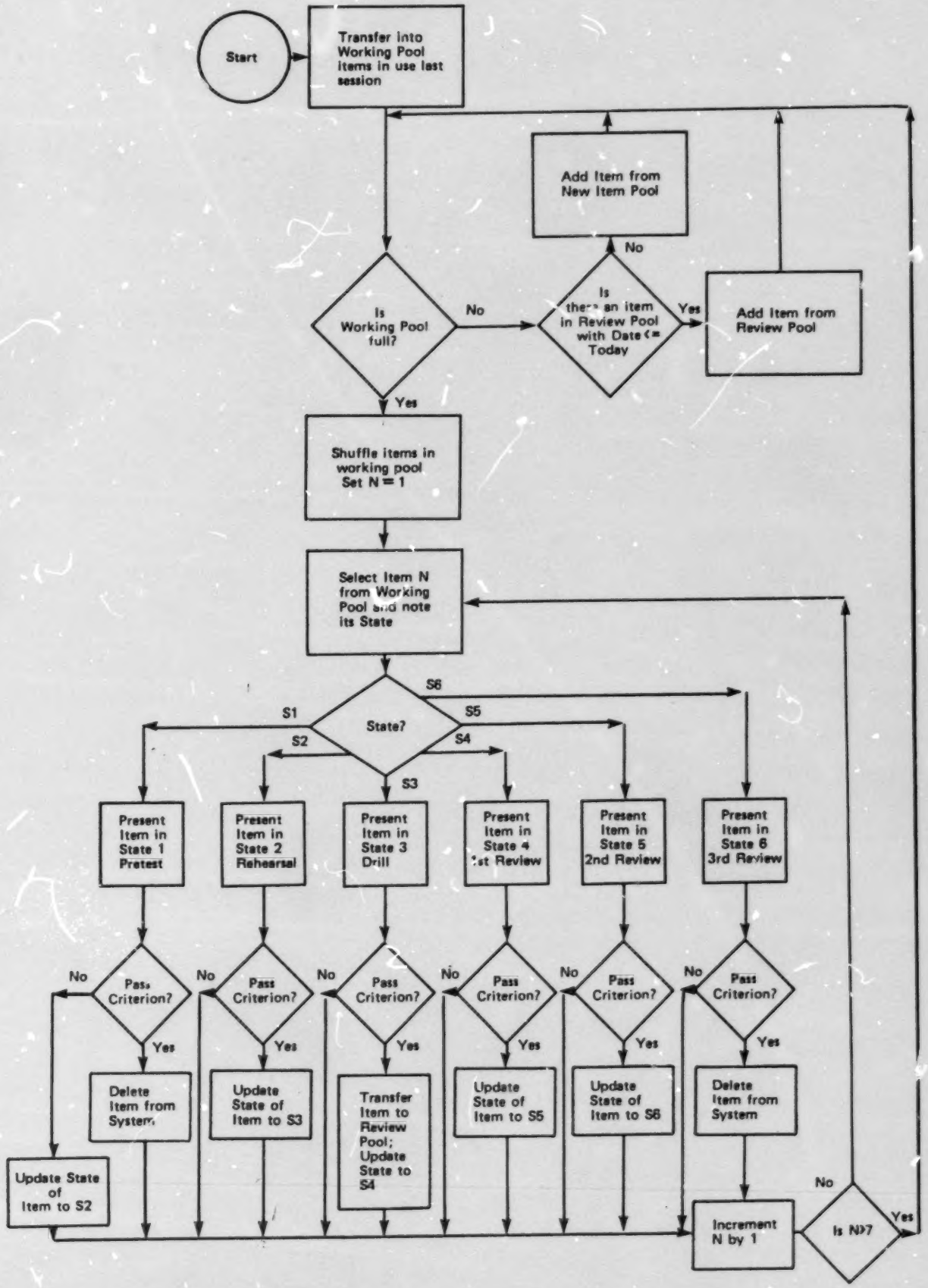
This is done by presenting items in six exercise formats. Optimization of the drill involves deciding which items to present, which exercise formats to present them in, and when to schedule review. This requires a complete response history for each student and use of this history to make trial-by-trial decisions regarding which items to present next.

Exercise formats include pretest format, rehearsal format, drill format, and three review formats. Figure 1 presents a flowchart showing the structure of the drill and the various exercise formats. To begin the drill, the working pool is filled with a specified number of items (usually 7 depending on the nature of the content and the ability level of the students). Then, the working pool is shuffled and an item is selected from the working pool and presented in the exercise format which corresponds to its state. Thus, the student works on a pool of items in which each item may be presented in a different exercise format depending on the student's response history for that item.

Items are first introduced as pretest items (state 1) in order to eliminate already known items from the drill. If an item is not eliminated it goes on to be presented in the other exercise formats. Items progress from one exercise format to the next by meeting the required response criterion for a particular format. Items which are mastered in drill format (state 3) become review items and will be reintroduced into the working pool periodically.

When a student begins a practice session any items left in his or her working pool from the last session are transferred from the disk to the current working pool. If the working pool is not full, then review items are brought in if there are any review items which have a review date less than or equal to today's date; otherwise, new items are

Figure 1. Flowchart for a Sophisticated Computer-based Drill and Practice Strategy (adapted from Atkinson, 1974).


Start
Transfer into Working Pool items in use last session
Add Item from New Item Pool
No
Is Working Pool full?
No
Is there an item in Review Pool with Date <= Today
Yes
Add Item from Review Pool
Yes
Shuffle items in working pool Set N = 1
Select Item N from Working Pool and note its State
State?
S1
S2
S3
S4
S5
S6
Present Item in State 1 Pretest
Present Item in State 2 Rehearsal
Present Item in State 3 Drill
Present Item in State 4 1st Review
Present Item in State 5 2nd Review
Present Item in State 6 3rd Review
Pass Criterion?
No
Yes
Update State of Item to S2
Delete Item from System
Update State of Item to S3
Transfer Item to Review Pool; Update State to S4
Update State of Item to S5
Update State of Item to S6
Delete Item from System
Increment N by 1
Is N>7
No
Yes

brought in to fill the working pool. In order to demonstrate the procedure for presenting the items in these various exercise formats a simplified example will be used. This example will consist of 15 items to be learned. These 15 items are labeled a through t.

A hypothetical student performance is shown in Table 2. The first row of the table shows the seven items included in the working pool at the start of the drill. The student responds to each item in the working pool and then the pool is shuffled. The contents of each succeeding working pool is determined by the response history of the student. Each row of the table shows the contents of the working pool as it changes dynamically throughout the drill. As indicated in Table 2, the student first attempts seven items: a, b, c, d, e, f, and g.

Table 2

Drill History for a Hypothetical Student

Working Pool	Working Pool Contents						
1	a10	B10	c10	D10	E10	f10	G10
2	a11 (drop)	b20	c11 (drop)	d20	e20	f11 (drop)	g20
3	H10	b30	I10	d30	e30	J10	G30
4	h20	b31	i20	d31	e31	j21	g30
5	h30	b32 (to review)	i30	D32	e32 (to review)	J30	G31
6	h31	K10	i31	D32	L10	j30	g31(stop)
	-Student quits and begins again the next day-						
7	h32 (to review)	k20	i32 (to review)	d32 (to review)	l20	j31	g32 (to review)
8	b40	K30	e40	n10	l21	j32 (to review)	o10

Note. Upper case letters indicate an incorrect response, lower case letters indicate a correct response. The first number following each letter indicates the state of the item before the response. The second number indicates the number of correct responses previously given to that item.

The numbers following each letter indicate the status of each item by giving its current state and response history within that state. The first number denotes the state and the second subscript indicates the number of times the student has responded correctly to the item. As shown in row one, the first time through the working pool each item (items a, b, c, d, e, f, and g) was presented in State 1 (pretest format). Therefore each of these items contain a one as the first number. The zero as the second number indicates that the learner has not yet responded correctly to any of these items.

In Table 2 a lower case letter is used to indicate that the student gives a correct response to the item. An upper case letter indicates that an incorrect response is given. Note that the numbers indicate the status of the item before a response, the letter indicates whether a correct or incorrect response is given to that item. Therefore, row one shows that the student responds correctly to pretest items a, c, and f but incorrectly to items b, d, e, and g. Table 3 shows the required response criteria for moving an item from one state to the next. The criterion setting for State 1 is two correct responses. Therefore, in working pool two items a, c, and f are presented again in State 1 but the criterion setting has now been updated to one, indicating one previous correct response.

Table 3

Required Response Criteria for Each Exercise Formats

Exercise Format (State)	Name of Format	Required Response Criteria
1	Pretest	2
2	Rehearsal	1
3	Drill	3
4	1st Review	2
5	2nd Review	2
6	3rd Review	2

In working pool one, the student did not respond correctly to items b, d, e, or g and so the second time through the working pool (row 2) these items are presented in State 2 (rehearsal format). With a criterion setting of zero meaning zero correct responses for this state. The working pool now contains item a in state 1, item b in state 2, item c in state 1, item d in state 2, item e in state 2, item f in state 1, and item g in state 2. The second time through the working pool the student responded correctly to pretest item a which will cause its criterion setting to be incremented to 2 and thus dropped from the drill because we can assume that the student already knows the item. The student also responds correctly to pretest items c and f so these will likewise be dropped from the drill. Item b is presented in rehearsal format (state 2) and the student gives a correct response. The student likewise gives a correct response to rehearsal items d, e, and g.

The third time through, the working pool consists of a new item (item h) which has been brought in to replace item a which the learner already knew. Items c and f have been replaced with new items, items i and j respectively. Item b is now presented in State 3 (drill format).

By studying Table 2, one can track the items through the various exercise states. Notice that by the time our hypothetical student quits the drill after going through working pool six, two items (items b and e) have been mastered and their state updated to Review State 4. When our student begins the drill the following day these items reenter the working pool as soon as a vacancy occurs. Item b, for example, reenters the drill as a review item (state 4) in working pool eight to replace item h. Item e also reenters at this time to replace item i. Items d and g are replaced with new items n and o because there are no more review items available.

All of the criterion settings in the computer program are adjustable for different applications. Optimal criterion settings would need to be determined empirically. Structuring the drill in this manner is consistent with the research implications described in this paper. Interference is reduced by presenting only a few items at once. Also, items to be presented can be selected in a specific sequence if desired in order to present similar stimuli together. The drill design allows for spaced practice because of its use of an individualized record for each student from session to session. This allows a particular student to pick up in the drill where they left off the previous session. Spaced review is provided through the use of multiple review states which present items to be reviewed at differing time intervals. The drill takes into account the capacity of short term memory by

requiring that the learner learn only a few items at a time while reviewing systematically previously mastered items.

Other drill strategies could certainly be designed around these implications. The degree to which computer drills consider these implications should influence their effectiveness and efficiency in leading toward skill automaticity.

Suggestions for Future Research

Computer drill and practice programs provide an opportunity to study learning and skill acquisition in ways which were not possible before. The computer enables one to design a drill and practice exercise that is much more sophisticated and complex than would be possible otherwise. The utilization of this technology for drill and practice raises questions that may be new or at least ones that have been relatively neglected.

Some of the research questions which need to be explored are:

1. How can computers assist in bringing about the integration of lower level component skills into a complex skill?
2. What type of computer drills can be used to maintain retention of a skill over a period of time.
3. What kind of practice most efficiently leads to skill automaticity?
4. What methods can be used in computer drills to space practice and review?
5. Can more imaginative and theoretically sound drill and practice programs replace the apparently weak system of dry and repetitive drills now available for microcomputers?

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